Improved Sanitizing Treatments for Fresh Tomatoes

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ABSTRACT: Fresh tomatoes repeatedly have been associated with major outbreaks of salmonellosis; however, efforts to disinfect them with chlorine or other sanitizing agents have had only mixed success. Our objective was to determine whether hydrogen peroxide (H_2O_2) treatments would be more efficacious than conventional methods in disinfecting tomatoes containing human pathogens and, at the same time, be noninjurious to quality. Tomatoes were dip inoculated with *Escherichia coli* NRRL B-766 or a *Salmonella* cocktail and then held for 0, 24, or 48 h at 4 or 24 °C prior to treatment. Treatments included 200 ppm chlorine (Cl_2) at 20 °C for 3 min, water at 20 °C for 3 min or at 60 °C for 2 min, 1% H_2O_2 at 20 °C for 15 min or at 60 °C for 2 min, and 5% H_2O_2 at 60 °C for 2, 3, or 5 min. In tomatoes held 48 h postinoculation, the chlorine treatment was only marginally more effective than an equivalent water rinse in reducing the target bacterial population, while the hot water and 1% H_2O_2 treatments achieved reductions no greater than 1.3 logs. However, application of 5% H_2O_2 at 60 °C resulted in larger reductions. Efficacy of all treatments decreased as the time interval between inoculation and treatment increased. Greater reductions could not be achieved with 5% H_2O_2 at 60 °C by increasing the contact time or addition of surfactants, and these treatments caused some quality loss.

Keywords: food safety, hot water, hydrogen peroxide, sanitizing treatments, tomatoes

Introduction

Fresh tomatoes have repeatedly been associated with major outbreaks of salmonellosis; multistate outbreaks occurring in 1990, 1993, 1998, 2002, and 2004 were responsible for more than 1300 cases (CDC 2002, 2005; Dewaal and Barlow 2002; FDA 2003, 2004; Srikantiah and others 2005). While the specific sources of contamination have not been identified, tomatoes are grown in natural habitats for *Salmonella* reservoirs (that is, birds, amphibians, reptiles) and may become contaminated preharvest or during packing from contaminated wash water (CDC 2005). *Salmonella* will attach to tomato surfaces and survive postcontamination storage (Wei and others 1995; Zhuang and others 1995; Iturriaga and others 2003; Lang and others 2004; Rathinasabapathi 2004). During cutting, *Salmonella* on the tomato surface can be transferred to interior surfaces where growth can occur (Asplund and Nurmi 1991; Wei and others 1995; Lin and Wei 1997). Efforts to disinfect tomatoes inoculated with *Salmonella* by sanitizing with a chlorine (Cl_2) wash have had mixed success, achieving high population reductions when the targeted pathogens were on the skin surface but smaller reductions when the pathogens attached to the stem scar or penetrated into the core (Wei and others 1995; Zhuang and others 1995; Beuchat and others 1998). Similar results were reported with other sanitizers including trisodium phosphate (Zhuang and Beuchat 1996), electrolyzed water (Bari and others 2003), a combination of lactic acid and hydrogen peroxide (H_2O_2) (Venkitanarayanan and others 2002), or a commercial produce wash (Harris 2001). Studies with *Erwinia carotovora* subsp. *carotovora*, a plant pathogen, and *Salmonella* Montevideo have demonstrated that if the tomatoes are submerged for a sufficient time in contaminated water, and the fruit temperature is higher than the water temperature, the water and bacteria contained therein will be infiltrated into the fruit interior as the fruit cools (Bartz and Showalter 1981; Wei and others 1995). The same infiltration process may be driven by hydrostatic pressure when tomatoes are submerged in contaminated water within a deep tank (Bartz 1982). In this internalized state, bacteria are protected from exposure to sanitizing washes (Ibarra-Sánchez and others 2004).

If the targeted human pathogens are attached within protected sites in the stem scar or core, a penetrating disinfection treatment might show greater efficacy than a simple wash. Hot water and radiation treatment have been used to control decay of tomato fruits (Halprin 1991; Barkai-Golan and others 1993). More recently, a hot water-brushing system was developed and commercialized for treatment of tomatoes and other commodities to reduce decay (Ilic and others 2001; Fallik and others 2002). Ibarra-Sanchez and others (2004) were able to decontaminate tomato surfaces with warm (55 °C) 2% lactic acid sprays. Previously we have been successful in disinfecting inoculated cantaloupes by surface pasteurization with water at 76 °C for 2 to 3 min, obtaining 5 log reductions in the population of *Salmonella* Poona (Annous and others 2004). In another study we obtained a 3.8 log reduction of *Salmonella* Poona on inoculated cantaloupe by treatment with 5% H_2O_2 at 70 °C for 60 s (Ukuku and others 2004). Heated solutions of 1% to 5% H_2O_2 also were effective in inactivating *E. coli* on dip-inoculated apples, achieving population reductions approaching 3 logs (Sapers and others 2002; Sapers and Sites 2003). Similar reductions were obtained when the apples were treated with the same solutions applied at 20 °C for 15 min (Sapers and Sites 2003). Our objective in the present study was to determine whether hot water and hot H_2O_2 treatments would be efficacious in disinfecting tomatoes containing human pathogens and at the same time be noninjurious to quality.

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Materials and Methods

Raw material source

Firm tomatoes at the light red stage of ripeness, free of external defects, were purchased from local food stores and stored in closed plastic bags for no more than 2 d in a refrigerator at about 4 °C. The tomatoes were removed from storage and equilibrated at ambient temperature (about 24 °C) for about 1 h prior to each experiment.

Preparation of inoculum

Initial experiments were carried out with *E. coli* NRRL B-766 (ATCC 9637), a nonpathogenic surrogate for *Salmonella* obtained from Dr. L. K. Nakamura (USDA-ARS-NCAUR, Peoria, Ill., U.S.A.). This organism was reported to have similar attachment, growth, and survival characteristics as several *Salmonella* strains (Eblen and others 2005). The surrogate was used to avoid risk of contamination of pilot plant personnel with a human pathogen during handling of large quantities of inoculated samples and exposure to splashes and aerosols from solutions used to treat these samples. *S.* Montevideo G4639 (1993 tomato outbreak) and *S.* Baildon 61-99 (1999 tomato outbreak) were obtained from Dr. Larry Beuchat (Univ. of Georgia Center for Food Safety & Quality Enhancement in Griffin, Ga., U.S.A.). Inocula were prepared from cultures maintained on tryptic soy agar (TSA; BBL/Difco, Sparks, Md., U.S.A.) by growing the organisms in tryptic soy broth (TSB; BBL/Difco) at 37 °C for 8 h, transferring 100 μL of the late exponential-phase culture to 1 L of TSB, allowing the cultures to grow with shaking at 90 rpm for approximately 18 h at 37 °C in an incubator shaker (Innova 4230, New Brunswick Scientific, Edison, N.J., U.S.A.), centrifuging the cultures at 6740 × *g* for 20 min, washing the pellets once with 200 mL sterile Millipore-purified (Milli-Q Lab Water System; Millipore Corporate Headquarters, Billerica, Mass., U.S.A.) deionized water (MDW), centrifuging a 2nd time at 6740 × *g* for 10 min, and resuspending the cells in 200 mL of sterile MDW. The resulting cell suspensions, when diluted to 2 L with sterile MDW, gave a final cell concentration of approximately 9 $\log_{10}$ CFU/mL, sufficient to result in a population size of about 5 $\log_{10}$ CFU/g on inoculated samples.

Method of inoculation

Sets of 4 or 5 whole tomatoes were dip inoculated within a biosafety cabinet by full submersion to a depth of about 5 to 10 cm below the surface for 5 min in a metal beaker containing 2 L of inoculum. The inoculated tomatoes were placed in a colander for draining with the stem scar area facing the side so that a pool of inoculum would not be retained, followed by air-drying in plastic tubs lined with absorbent towels for 1 h with the tomatoes in an upright position. Following air-drying, the tubs were covered tightly with aluminum foil, and the tomatoes were either taken to the pilot plant for treatment (applied about 2 h after completion of drying), or the covered tubs were stored at 4 °C or room temperature (about 24 °C) for 24 or 48 h.

Application of treatments

Washing trials with tomatoes inoculated with the nonpathogenic *E. coli* strain were conducted in a biosafety level 2 pilot plant where suitable equipment was located. Duplicate sets of 4 tomatoes, inoculated with *E. coli*, were either transferred to 2-gal. zipper-close type plastic bags (Hefty®; Pactiv Corporation, Lake Forest, Ill., U.S.A.) and used as untreated controls or were transferred to a stainless steel basket fitted with a lid and fully submerged for 4 min to a depth of about 30 to 50 cm in a stainless steel dump tank containing 1000 L water (city tap water) at 20 °C with gentle vertical motion to provide agitation, drained, and packed in the plastic bags as rinsed controls. Additional duplicate sets of 4 tomatoes, placed within the stainless steel basket, were submerged with agitation in a stainless steel tank containing 120 L of treatment solution. Treatments included (1) deionized water (DW) at 60 °C for 2 min; (2) 0.35% Clorox® containing 6% sodium hypochlorite (The Clorox Company, Oakland, Calif., U.S.A.), adjusted to pH 6.5 with 1 M HCl and applied for 3 min at 20 °C; the free Cl_2 concentration in the freshly prepared solution was determined to be 200 ppm by the CHEMetrics Kit No. K-2505B (CHEMetrics Inc, Calverton, Va., U.S.A.); (3) 1% H_2O_2 applied for 15 min at 20 °C or for 2 min at 60 °C; and (4) 5% H_2O_2 applied for 2, 3, or 5 min at 60 °C. To determine whether addition of wetting agents enhanced the efficacy of H_2O_2 treatments, 0.1% to 0.5% sodium salts of 2-ethyl hexyl sulfate (Stepanol® EHS, Stepan Company, Northfield, Ill., U.S.A.), dodecylbenzene sulfonic acid (Sigma Chemical Co., St. Louis, Mo., U.S.A.), or dioctyl sulfosuccinate (Sigma) were added to 5% H_2O_2 at 60 °C, and samples were treated for 2 min. All treated samples were rinsed in DW for 1 min to remove residual wetting agent, Cl_2, or H_2O_2, which might interfere with subsequent microbiological procedures. After draining, rinsed samples were transferred from the basket to the 2-gal. zipper-close plastic bags for later enumeration of bacteria.

Disinfection trials with tomatoes inoculated with the *Salmonella* cocktail were conducted in a microbiology lab using benchtop equipment and smaller quantities of samples and solutions to minimize the risk of contamination of laboratory personnel. Hot water and peroxide solution applications were carried out by submerging sets of 4 tomatoes to a depth of 20 to 30 cm in an insulated stainless steel processing vessel (internal dia, 0.41 m, and height, 0.61 m) containing 75 L of solution, heated to 60 °C (±0.5 °C) with a 3000 watt electric immersion heater, and with gentle mixing provided by a centrifugal pump, as previously described (Solomon and others 2005). This system was capable of maintaining the treatment temperature, even upon addition of tomatoes to the water. Preparation of rinsed controls and treatment with 200 ppm Cl_2 were carried out at 20 °C by dipping inoculated samples placed in stainless steel baskets into cylindrical tubs (21 L capacity; high density polyethylene) containing 10 L of DW or Cl_2 solution. Samples were drained and rinsed by successive immersion in 2 cylindrical tubs (see above), each containing 10 L of DW.

Treated samples and corresponding controls were observed for visual evidence of discoloration or other surface defects, loss of firmness (as perceived during handling), or off-odors.

Recovery and enumeration of bacteria. Control or treated sets of 4 tomatoes were weighed, combined with sterile 1 % buffered peptone water (PW; BBL/Difco) at a 1:1 ratio in a 4-L stainless steel Waring blender (Waring Products Div., Dynamics Corp. of America, New Hartford, Conn., U.S.A.) container, and homogenized at medium speed for 1 min. Blended samples were filtered through a sterile filter bag designed for microbiological examination of particulate suspensions (40 μm pore size; Spiral Biotech, Bethesda, Md., U.S.A.), and the filtrates were serially diluted with sterile 0.1% PW, as required. Generic *E. coli* counts were obtained by spread plating in duplicate 0.1 mL aliquots of diluted homogenate filtrate on TSA, incubating for a minimum of 2 h at 37 °C to allow injured cells to recover, and then overlaying with MacConkey agar (MAC; BBL/Difco) and incubating overnight at 37 °C. *Salmonella* counts were obtained by the same procedure as for *E. coli* but with an overlay of xylose lysine Tergitol-4 agar (XLT-4, BBL/Difco), also incubating overnight at 37 °C.

Statistical analyses

Population reduction data were analyzed for differences in response to treatments by analysis of variance (ANOVA) and the least

significant difference (LSD) test to separate means. All statistical analyses were performed with SAS/STAT software (SAS Institute Inc. 1989).

Results and Discussion

Immersion of tomatoes inoculated with *E. coli* NRRL B-766 in water with vigorous agitation was only marginally effective in detaching this organism, yielding population reductions of <1 log (Table 1). Application of 200 ppm Cl_2 under the same conditions resulted in significant population reductions ($P < 0.05$) between 1 and 2 $\log_{10}$ CFU/g. Population reductions were greater when these treatments were applied at zero time (2 h after inoculation and air drying) compared to reductions obtained after storage of tomatoes for 48 h at 4 °C. These reduction levels would be insufficient to ensure microbiological safety.

Additional washing trials were conducted with hot water (60 °C) and hydrogen peroxide solutions, applied at ambient temperature or heated to 60 °C. Treatment of inoculated tomatoes with 1% H_2O_2 at 20 °C for 15 min, a treatment previously found to be effective in inactivating *E. coli* on inoculated apples (Sapers and Sites 2003), yielded population reductions no greater than 1.4 logs (Table 2). Application of this treatment at 60 °C for 2 min yielded population reductions approaching 2 logs when the tomatoes were treated at zero time ($P < 0.05$); however, reductions were smaller when samples were held for 48 h at ambient temperature following inoculation. Improved population reductions were obtained when the H_2O_2 concentration was increased to 5% ($P < 0.05$), but even with this treatment was less effective following postinoculation storage. Population reductions obtained by treatment of inoculated tomatoes with water at 60 °C were ≤ 1 log, comparable in magnitude to the reductions obtained by rinsing with water at 20 °C (Table 1).

In experiments intended to enhance the efficacy of 5% H_2O_2 at 60 °C, we obtained minimal gains by extending the treatment time from 2 to 3 or 5 min (Table 3). Firm, slightly under-ripe tomatoes, subjected to treatment with 60 °C water or solutions of 5% H_2O_2 for 2 or 3 min, showed no evidence of physical damage immediately following treatment. However, some darkening and softening of the skin was observed with 5 min treatment time and when the 60 °C treatments were applied to tomatoes of greater ripeness. In the latter case, the microbiological data were not used. Thus, the applicability of this treatment is restricted to under-ripe tomatoes, and use of extended treatment times at 60 °C or of treatment temperatures in excess of that temperature to achieve greater population reductions is not feasible. The possibility of treatment-induced quality changes occurring during posttreatment storage was not investigated in this study.

Table 1 — Efficacy of water rinse and 200 ppm Cl_2 treatment in reducing the population of *E. coli* NRRL B-766 on dip-inoculated tomatoes, as affected by postinoculation storage at 4 °C[a]

Treatment[b]	Storage (h)	Population ($\log_{10}$ CFU/g)[c]	Population reduction ($\log_{10}$ CFU/g)[d]
Control	0	5.82 ± 0.14	—
	48	5.14 ± 0.45	—
Rinsed control	0	4.90 ± 0.28	0.92 BC
	48	4.54 ± 0.57	0.60 C
200 ppm Cl_2	0	4.12 ± 0.76	1.70 A
	48	3.98 ± 0.19	1.16 AB

[a]Inoculum population was 9.96 ± 0.26 $\log_{10}$ CFU/mL ($n = 4$).
[b]Rinsed controls rinsed in H_2O for 4 min at 20 °C; 200 ppm Cl_2 samples treated for 3 min, then rinsed in H_2O for 1 min at 20 °C.
[c]Population means for 4 to 6 replicate trials ± standard deviations.
[d]Means in the Population reduction column, not followed by the same letters, are significantly different ($P < 0.05$).

Table 2 — Efficacy of H_2O_2 in reducing the population of *E. coli* NRRL B-766 on dip-inoculated tomatoes, as affected by postinoculation storage at 20 °C[a]

Treatment	Storage (h)	Population reduction ($\log_{10}$ CFU/g)[b,c]
1% H_2O_2 at 20 °C for 15 min	0	1.41 ± 0.47 CDE
	24	1.04 ± 0.52 EF
	48	1.12 ± 0.75 E
1% H_2O_2 at 60 °C for 2 min	0	1.80 ± 0.43 BC
	24	1.77 ± 0.55 BCD
	48	1.25 ± 0.54 DE
5% H_2O_2 at 60 °C for 2 min	0	2.64 ± 0.42 A
	24	2.10 ± 0.38 AB
	48	2.04 ± 0.49 BC
H_2O at 60 °C for 2 min	0	0.93 ± 0.36 EF
	24	0.99 ± 0.36 EF
	48	0.50 ± 0.44 F

[a]Inoculum population was 8.86 ± 0.19 $\log_{10}$ CFU/mL ($n = 15$).
[b]Mean population reductions ± standard deviations based on corresponding control means for 3 to 5 independent experiments, each with duplicate trials; control means were 5.57 ± 0.23, 5.12 ± 0.31, and 5.62 $\log_{10}$ CFU/g for 0-time, 24 h, and 48 h, respectively.
[c]Means not followed by the same letters are significantly different ($P < 0.05$).

Addition of wetting agents increased the variability of treatments with 5% H_2O_2 at 60 °C, with minimal improvements and some reductions in treatment efficacy (Table 3). In addition, off-odors were noted with sodium 2-ethyl hexyl sulfate addition, and sodium dodecyl benzene sulfonic acid produced excessive foaming. Sodium dioctyl sulfosuccinate treatment left residues on tomatoes that were difficult to remove by rinsing; consequently, data from this treatment were not reported.

Washing trials with tomatoes inoculated with the *Salmonella* cocktail yielded results similar to those obtained with the *E. coli* strain (Table 4). Log reductions were greater ($P < 0.05$) when treatments were applied at zero time than after 24 h. At zero time, 5% H_2O_2 at 60 °C was more effective ($P < 0.05$) than water at 60 °C, 200 ppm Cl_2, or a water rinse. However, after 24 h the treatments were not significantly different.

Reduction levels (2.6 $\log_{10}$ CFU/g) obtained with 5% H_2O_2 at 60 °C for both *Salmonella* and *E. coli* at zero time, corresponding to freshly contaminated tomatoes, might be expected to significantly reduce the risk of foodborne illness. This might apply if tomatoes were exposed to contaminated water in flumes or wash

Table 3 — Effect of treatment time and surfactant addition on efficacy of 5% H_2O_2 in reducing population of *E. coli* NRRL B-766 on dip-inoculated tomatoes held 24 h at 20 °C prior to treatment[a]

Treatment[b]	Treatment time (min)	Population reduction ($\log_{10}$ CFU/g)[c,d]
5% H_2O_2 at 60 °C	2	1.44 ± 0.35 AB
5% H_2O_2 at 60 °C	3	0.95 ± 0.62 AB
5% H_2O_2 at 60 °C	5	1.90 ± 0.66 A
5% H_2O_2 at 60 °C[e]	2	1.14 ± 0.65 AB
5% H_2O_2 + 0.1% SHS at 60 °C	2	1.93 ± 1.08 A
5% H_2O_2 + 0.5% SHS at 60 °C	2	1.88 ± 1.10 A
5% H_2O_2 + 0.1% DBSA at 60 °C	2	1.12 ± 0.53 AB
5% H_2O_2 + 0.5% DBSA at 60 °C	2	0.70 ± 0.79 B

[a]Inoculum population was 9.71 ± 0.22.
[b]SHS = sodium 2-ethyl hexyl sulfate; DBSA = sodium dodecyl benzene sulfonic acid.
[c]Mean population reductions ± standard deviations based on corresponding control means for 3 independent experiments, each with duplicate trials; control means were 5.17 ± 0.12 $\log_{10}$ CFU/g for the treatment time comparisons and 5.37 ± 0.39 for the surfactant trials.
[d]Means not followed by the same letters are significantly different ($P < 0.05$).
[e]Mean population reductions for 5% H_2O_2 treatments carried out along with the surfactant addition trials.

Table 4—Efficacy of wash treatments in reducing population of *Salmonella* on dip-inoculated tomatoes[a]

Treatment	Storage (h)	Population reduction (log_{10} CFU/g)[b,c]
Rinsed control at 20 °C for 2 min	0	1.11 ± 0.18 C
	24	0.40 ± 0.32 D
200 ppm Cl_2 at 20 °C for 2 min	0	1.78 ± 0.49 B
	24	1.34 ± 0.39 BC
5% H_2O_2 at 60 °C for 2 min	0	2.59 ± 0.74 A
	24	1.45 ± 0.33 BC
H_2O at 60 °C for 2 min	0	1.75 ± 0.11 B
	24	0.99 ± 1.00 CD

[a]Inoculum prepared from a cocktail containing *S.* Montevideo (G4639) and *S.* Baildon (61–99); mean inoculum population was 10.13 ± 0.04 for the treatment comparisons.
[b]Mean population reductions ± standard deviations based on corresponding control means for 2 or 3 independent experiments, each with duplicate trials; control means were 5.61 ± 0.27 and 5.42 ± 0.26 log_{10} CFU/g for the 0-time and 24-h treatment time comparisons, respectively.
[c]Means not followed by the same letters are significantly different ($P < 0.05$).

tanks immediately prior to application of a sanitizing treatment. However, even the H_2O_2 treatment would be incapable of achieving sufficiently large reductions to ensure product safety when the interval between tomato contamination and sanitizing was 24 h or more. We suspect that this storage effect is due to internalization of bacteria in the stem scar area, which may prevent contact by treatment solutions, and perhaps to formation of resistant biofilms during the interval between inoculation and treatment. Similar storage effects were observed in previous studies with apples (Sapers and others 2000) and cantaloupes (Ukuku and Sapers 2001; Ukuku and others 2001).

It is difficult to compare the results of this study with other studies because of differences in inoculum strength, the time interval between inoculation and treatment, treatment conditions, and the method of recovery (for example, rinsing, rubbing, and/or blending). Zhuang and others (1995) reported reductions in *S.* Montevideo of about 1.2 logs on tomato skin and 0.8 on tomato core when treated 18 h after dip inoculation with sodium hypochlorite solutions comparable to those used in our study. Beuchat and others (1998) applied 200 ppm free Cl_2 to dip-inoculated tomatoes 18 to 22 h postinoculation by spraying followed by soaking for different times. They reported reductions of about 1.5 for *E. coli* O157:H7 and 1.0 for naturally occurring aerobic mesophiles treated with a 3 min soak time. Wei and others (1995) spot inoculated tomato skin and stem scars with *S.* Montevideo, and after 20 h dipped the tomatoes in 100 ppm free Cl_2 solution. They reported reductions of 1.7 logs on the skin but only 0.6 logs at the stem scar. These results are comparable to those obtained with 200 ppm Cl_2 in the present study.

We are not aware of any other studies employing H_2O_2 alone as a sanitizing agent for tomatoes. Venkitanarayanan and others (2002) reported population reductions exceeding 5 logs on tomatoes, spot inoculated with *S. enteritidis, E. coli* O157:H7, and *Listeria monocytogenes*, when the tomatoes were immersed in 1.5% H_2O_2 plus 1.5% lactic acid at 40 °C for 15 min. However, the short 1 h interval between inoculation and treatment probably would have been insufficient for internalization in the stem scar area (if the spots were applied directly on the stem scar) or for development of resistant biofilms. Thus, the absence of these conditions may explain the exceptionally large population reductions obtained. The elevated temperature may also have contributed to these reductions. In a similar study Ibarra-Sánchez and others (2004) reported the high efficacy of warm (55 °C) lactic acid sprays in decontaminating dip inoculated tomatoes containing *S. typhimurium* and *E. coli* O157:H7 on the surface and internalized in the stem scar. However, the very short (approximately 20 min) interval between inoculation and treatment may have contributed to their success by limiting microbial attachment, diffusion, and biofilm formation. Similarly, a short interval (1 h) between inoculation and treatment may explain the high recovery and inability of surfactants to improve on the detachment of *Salmonella* and *Shigella* from dip-inoculated tomatoes by rinsing with water (Raiden and others 2003).

Most of the reported hot water treatments for produce employed somewhat lower temperatures than were employed in the present study and were intended for insect disinfestation or to reduce decay. An innovative hot water treatment, rinsing while brushing at 52 °C for 15 s or dipping in 52 °C for 1 min, significantly reduced decay development in tomatoes and did not affect quality parameters such as fruit firmness, total soluble solids, or acidity (Ilic and others 2001). Dipping inoculated tomatoes in hot water at 50 °C for 2 min was very effective in reducing *Botrytis cinerea* and *Rhizopus stolonifer* decay (Barkai-Golan and others 1993). In the present study, the 60 °C water treatments showed limited efficacy against *E. coli* and *Salmonella* strains although treatment at this temperature may have enhanced the efficacy of 5% H_2O_2.

Conclusions

Population reductions obtained in freshly inoculated samples by treatment with 5% H_2O_2 at 60 °C were higher than those obtained with 200 ppm free Cl_2. However, the dependence of treatment efficacy on the time interval between inoculation and treatment application represents an important limitation of these treatments. Our results confirm the need for more efficacious disinfection treatments that are capable of inactivating human pathogens on tomatoes when the interval between contamination and treatment is sufficiently great to allow for increased microbial survival.

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